Chewing Activity by Dairy Cows In Response to Particle Size of Diets and Intakes of Neutral Detergent Fiber and Forage Neutral Detergent Fiber

HONORS RESEARCH PROJECT

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TABLE OF CONTENTS

Abstract

Proper rumen function is necessary for maintaining overall health of dairy cows. Rumen function is dependent on rumen pH being in the range of 6.2 to 6.5, which is regulated by the amount of time spent chewing. Chewing activity is stimulated by intake of forages and to a lesser extent by particle size of the diet. Nonforage fiber sources, specifically soyhulls and whole cottonseed (WCS), were investigated for their ability to stimulate chewing when used to replace a portion of both forages and concentrates in the diets for lactating dairy cows.

Forty-four lactating dairy cows were randomly assigned and fed one of the four following diets that were formulated to contain: 1) 21% forage NDF (FNDF) with corn, 2) 16% FNDF with corn, 3) 16% FNDF with a 1:1 ratio of corn and wheat, and 4) 11% FNDF with corn and whole cottonseed (WCS). The mean particle size (MPS) was measured for all of the diets.

Total time spent chewing per kg of both FNDF and NDF was also determined. The MPS was decreased by the addition of soyhulls and WCS in place of a portion of forage and concentrate in the diets. Total time spent chewing was not significantly different between the diets. Results of the study indicate that the addition of soyhulls and WCS were able to effectively replace a portion of forages and concentrate in the diets of lactating dairy cows and still maintain total time spent chewing and therefore proper rumen function.

Literature Review

Proper rumen function in dairy cows is necessary to obtain maximum milk production. Rumen function is maintained by the normal microbial population that inhabits the rumen. These microbes are responsible for feed degradation. Although rumenal microbes function optimally at a pH of 6 to 7, the end products of carbohydrate fermentation, which are volatile fatty acids (VFA) and lactic acid, lower the pH in the rumen. The production of saliva acts as a buffer to help keep the pH stable (Wattiaux, 1996). There should be enough saliva produced to counteract the affects of the VFA. The amount of saliva produced is a direct result of the chewing activity of the cow, which is stimulated by the diet. A dairy cow will typically chew six to eight hours a day, resulting in 160 to 180 liters of saliva (Wattiaux, 1996).

Dairy cow diets consist of concentrates, forages, and byproducts. Concentrates, which are high energy and low fiber feeds, provide the energy needed by the cows to maintain optimum milk production (Wattiaux, 1996). However, these feeds stimulate little chewing activity and lower the pH of the rumen. Forages, which are high in fiber and low in energy, stimulate chewing activity and are needed to compensate for the lowered pH of the rumen caused by high levels of concentrate in the diet.

Concentrates should only account for 40 to 60% of the total diet (Grant, 1995b). When concentrates comprise more than 60% of the dry matter intake (DMI), problems arise such as decreased pH, laminitis, ketosis, displaced abomasum, and feed intake fluctuations. The maximum dietary level of nonfibrous carbohydrates (NFC), the major component of a typical concentrate, should be 45% (Howard and Wattiaux, 1996a). The NFC, such as starch, are generally more rapidly digested than fiber. These factors increase the acidity of the rumen and cause a decrease in the fiber digestion and chewing activity needed for proper rumination (Mertens, 1992). Fibrous feed is necessary for maintaining rumination and chewing activity. Therefore, total dietary level of NDF should be greater than 25 to 28%, with at least 75% of the NDF coming from forages, or a minimum dietary level of FNDF at 18 to 21% (NRC, 1989). The NDF is slowly digested, occupying space in the rumen and limiting feed intake (Mertens, 1988). The NDF is inversely related to NFC: NFC = DM - (NDF + CP + fat + ash) (Howard and Wattiaux, 1996b). This becomes a problem when trying to meet the animal's energy requirement and to stimulate chewing to neutralize the pH of the rumen. Ideally, diets should contain the minimum amount of forages necessary to maintain rumen function, while maximizing the energy intake to maintain optimum milk production.

The amount of forages is not the only factor, however, that plays a role in stimulating chewing. Chewing activity is thought to be positively related to the particle size of the feed. Decreasing particle size of forage was found to reduce time spent chewing in a study conducted by Grant et al. (1990). This reduction in particle size also increased the passage rate from the rumen, lowering DM digestibility. Small particle size seems to encourage rapid rumen escape, thereby reducing rumination and saliva production (Grant, 1995a). As a result, Howard and Wattiaux (1996a) suggested that an adequate particle length of at least 2.5 cm is necessary to effectively stimulate chewing.

Nonforage fiber sources (NFFS) can be used as alternative feeds to replace either starch or forages. Replacing starch with NFFS can reduce ruminal acidosis, and replacing forages with NFFS can extend forage supplies (Grant, 1995a). The NFFS have a higher passage rate from the rumen due to smaller particle size and denser particles, making them less effective at stimulating chewing than forage. Sarwar et al. (1991) suggested that 65% of the dietary NDF as forage may be sufficient in dairy rations containing NFFS. The NFFS can replace part of the forage in diets if part of the NFC is also replaced by fiber from NFFS (Firkins, 1995). According to Firkins (1995), if FNDF is decreased from the minimum requirement of 21% to 16% of dietary DM, then the amount of NFC should be decreased proportionally by a factor of 1.5 to maintain rumen function.

Types of NFFS that have been shown to be effective are cottonseed, soyhulls, corn gluten feed, and wheat middlings. Cottonseed seems to be the best forage substitute due to its physical resemblance to forage (Firkins, 1995). Cottonseed has been shown to be about 85% as effective as forage in stimulating chewing activity while soyhulls are 20% as effective (Mertens, 1992). Corn gluten feed can also be used to replace forage such that 35% of dietary NDF is contributed by corn gluten feed (Sarwar et al., 1991). Wheat middlings, as a fibrous energy source, have been thought to be able to replace 15% of the corn silage in a diet containing 50% of the DM as corn silage (Wagner et al., 1993).

Ideally, dairy cow diets consist of high energy concentrates to support optimum milk production. However, due to the necessity of maintaining pH for proper rumen function, this is not possible. Efforts are being made to keep forage intake at a minimum level by replacing forages with combinations of NFFS. The most important aspect about forage is its roughage value (Grant, 1995b). Further research needs to be conducted to determine if combinations of alternative feeds higher in energy can match the roughage value of forage and therefore have the same buffering capacity, or if the benefit of NFFS is their ability to dilute fermentable starch in diets.

Hypothesis: Replacing a portion of the forages and concentrates with NFFS in the diets of lactating dairy cows will decrease mean particle size of the diets. A decrease in mean particle size and percentage of FNDF in the diets will decrease total time spent chewing.

MATERIALS AND METHODS

Forty-four lactating Holstein cows housed in a tie-stall barn were blocked by parity and calving date and randomly fed one of four experimental diets formulated by Slater (1998). The diets were as follows: 1) 21% FNDF with corn 2) 16% FNDF with corn, 3) 16% FNDF with a 1:1 ratio between corn and wheat, and 4) 11% FNDF with corn and 11.2% of whole, linted cottonseed. Ingredient composition of the diets is shown in Table 1. Diets were fed during weeks 10 to 25 of lactation. Diet 1 served as a control and was balanced to contain 28% NDF and 42% NFC. In Diets 2 to 4, either soyhulls or linted cottonseed were used as byproducts to replace a portion of NDF and NFC. During ration formulation, the NDF in Diets 2 to 4 was increased to 35% of the diet while NFC was subsequently decreased to 35%. Chewing activity was observed and measured for each diet to compare effects of FNDF, total NDF, and particle size of the diets in relation to stimulation of chewing. This research was a sub-experiment to a graduate thesis (Slater, 1998). Chewing was defined as the total time spent eating and ruminating. Observations were made for a 24-hour period. Time spent in the milking parlor was not considered; therefore, actual observations were made for 18 hours. The 18-hour period was divided into three-hour shifts over the course of two days. Observations were made at five minute intervals for time spent lying, standing, eating, and ruminating. Due to displaced abomasum, three cows were dropped from the experiment. A randomized complete block design was used, and observations for forty-one cows were then analyzed using the General Linear Model procedure of SAS (1988). Mean particle size was measured and calculated for each experimental diet and for the alfalfa and corn silages using an oscillator with six different sieve sizes ranging from 150 to 4750 um. Mean particle size was calculated from four different separations of each diet on both a DM and as-fed basis (Waldo et al, 1971).

RESULTS AND DISCUSSION

The chemical composition of the diets is shown in Table 2. The FNDF concentration in the diets was lower than formulated due to an increase in the quality of alfalfa silage during the experiment. Actual FNDF concentrations for Diets 1, 2, 3, and 4 were 17.8, 14.0, 13.9, and 9.4%, respectively.

Dry matter intake (DMI) and the summary of observed behaviors are shown in Table 3. Cows consuming Diet 4, which contained the least amount of forage, had the highest DMI, although DMI was not statiscally analyzed. Cows consuming Diets 1 and 3 showed the least DMI. Forage is slowly degraded in the rumen, resulting in rumen fill, which decreases DMI. Cows consuming Diet 4 consumed the least amount of forage and therefore showed the highest intake in DM while cows consuming Diet 1 consumed the greatest amount of forage, resulting in a decreased DMI. Diet 3 had less forage than Diet 1; however, Diet 3 contained wheat, which is more rapidly degraded in the rumen than corn. The addition of wheat may have resulted in an increase in acidic conditions in the rumen, decreasing DMI.

Forage NDF intake was greatest for the cows on the control diet (Diet 1). The FNDF intake was least for the cows consuming 11% FNDF with WCS (Diet 4). The portion of NDF from forges in Diet 4 was lower than the other diets, resulting in a lower FNDF intake. Similarities in FNDF intake for cows fed the control diet and Diet 2 were as expected. Diet 2 contained a lower percentage of forages than Diet 1; however, the cows on Diet 2 consumed more total feed than the cows on Diet 1. This increase in DMI may have been enough to result in the consumption of a similar amount of forages by the cows on Diets 1 and 2. Similarities in FNDF intake also existed between cows fed Diet 2 and 16% FNDF with corn and wheat (Diet 3). However, there was a significant difference in FNDF intake between Diets 1 and 3. Even though there is not a significant difference in FNDF intake between Diets 2 and 3, cows on Diet 3 showed a slightly lower intake of FNDF. Diets 2 and 3 contained the same amount of forage, however, a probable increase in acidic conditions in the rumen due to the addition of wheat decreased DM intake for cows fed Diet 3. This decrease in intake may have decreased intake of FNDF enough to make it significantly different from the control diet but not enough to make it different from Diet 2.

Results of NDF intake were as expected. The cows consuming Diet 4 showed the greatest intake of NDF. This is due to higher DMI and a higher proportion of NDF in the diet (Table 2). The control diet contained the least amount of total NDF as well as the greatest amount of FNDF. As expected, cows consuming the control diet consumed the least amount of NDF. Cows consuming the diets intermediate in levels of both FNDF and NDF were intermediate in their intake of NDF

Time spent chewing per kilogram of FNDF and NDF differed among the diets; however, there were no differences among the diets for time spent standing, lying, eating, ruminating, and total chewing (Table 3). These results indicate that replacing forage and concentrate with soyhulls and WCS stimulated enough chewing per kilogram of FNDF and NDF to effectively stimulate total chewing overall. The cows which consumed the least amount of FNDF (Diet 4) spent more time eating, ruminating and total time chewing per kilogram of FNDF. Even though NDF does stimulate some chewing, the amount of NDF from forages probably has a bigger impact on total time spent chewing, although it was not significantly higher for the control diet in this study. When NDF from forages is compromised in the diet, cows compensate for this situation by chewing more per kilogram of FNDF (Grant, 1997).

Cows consuming the control diet spent more time chewing per kilogram of NDF than the cows consuming the other three diets (Figure 1). The NDF from NFFS is not as effective at stimulating total chewing (ruminating + eating) as the NDF from forages. Therefore, cows fed the control diet, which contained the least amount of NDF from NFFS, chewed more per kilogram of NDF. Cows fed 16% FNDF diets (Diets 2 and 3) resulted in similar chewing per kilogram of NDF. This was expected due to similar amounts of NDF from NFFS in these diets. However, cows fed 16% FNDF (Diet 2) with corn spent similar amounts of time chewing per kilogram of NDF as the cows fed 11% FNDF with WCS (Diet 4). Although cows fed Diet 4 consumed the greatest amount of NDF from NFFS, the addition of cottonseed was able to effectively stimulate chewing. This would also simulate a decrease in the amount of NDF from NFFS, making Diet 4 similar in FNDF intake to Diet 2. This suggests that the addition of cottonseed may have been able to simulate a concentration of 14.3% FNDF in the diet.

Mean particle size (MPS) of the diets on both an as-fed and DM basis is shown in Table 4. Typically, MPS is measured on an as-fed basis in order to identify the particle size of the diets in the actual form that it is fed tothe cows. Mean particle size was also measured on a DM basis to compare differences in MPS between the as-fed and DM basis. Differences in MPS between the as-fed and DM basis were larger than expected (Figure 2). Diet 1, which contained the greatest amount of forages, showed the greatest difference in particle size between the as-fed and DM basis. This may have been due to the breakage of forages during the particle separations on the DM basis. Measurements of MPS for the different diets were as expected. Mean particle size on an as-fed basis was 2.99, 2.02, 2.01, and 2.21 mm for Diets 1, 2, 3 and 4, respectively. Replacing FNDF with soyhulls and cottonseed decreased MPS of the diets. The addition of WCS was more effective at physically replacing forages than was soyhulls due to less of a decrease in MPS of the diet. Decreasing MPS did not seem to have an affect on the observed behavior of cows due to similarities in time spent lying, standing, eating, ruminating, and total chewing. The MPS does not seem to come into play for effectively stimulating total chewing unless effective fiber is compromised in the diet.

CONCLUSION

Byproducts, specifically soyhulls and whole cottonseed, were looked at for their ability to stimulate total chewing when used as a replacement for a portion of both forages and concentrates in the diets for lactating dairy cows. Replacing forages and concentrates with NFFS did decrease mean particle size. However, decreasing mean particle size and percentage of forage in the diets did not decrease time spent chewing. Results of the study indicate that the addition of soyhulls and WCS were able to effectively replace a portion of forages and concentrates in the diets and still maintain total time spent chewing, and therefore, proper rumen function. Byproducts, therefore, can give dairy farmers an opportunity to replace forages with lower cost fiber sources when economically desirable and still maintain herd health and optimum milk production.

Ingredient	Covariate Diet	21 % FNDF[1] with corn	16 % FNDF with corn	16 % FNDF with corn and wheat	11 % FNDF with WCS
	--------------------------	-----	% of DM	-----	--------------------------
Alfalfa silage	11.9	16.8	13.6	13.6	9.2
Corn silage	26.9	27.2	20.3	20.4	13.6
Dry shelled corn	6.2	30.6	22.9	13.8	27.2
Conmercial supplement[2]	51.4	...	...	...	...
Wheat	...	...	...	13.8	...
Soybean meal, 44% CP	3.6	15.9	12.5	8.8	10.0
Soyhulls	...	3.4	23.0	23.0	23.9
Whole cottonseed	...	...	...	...	11.0
Corn gluten meal	...	0.28	1.80	0.50	0.90
Blood meal	...	1.83	2.03	2.02	2.02
Tallow	...	1.95	1.97	1.96	...
Limestone	...	1.18	1.10	1.14	1.34
Magnesium oxide	...	0.14	0.14	0.16	0.10
Potassium sulfate	...	0.12	0.14	0.16	0.14
Vitamin A, D and E[3]	...	0.10	0.10	0.10	0.10
TM salt[4]	...	0.50	0.50	0.50	0.50

[1]FNDF = forage NDF.
[2]Contained 20.0% of CP, 38.6 % of NDF, 19.0 % of ADF, 0.78 % of P, 1.30 % of K, 1.31 % of Ca, 0.52 % of Mg, 0.18 % of S, 0.40 % of Na, 0.52 % of Cl, 96 ppm of Mn, 169 ppm of Fe, 22 ppm of Cu, 193 ppm of Zn, .70 ppm of Se, 16,506 IU/kg of vitamin A, 4,125 IU/kg of vitamin D, 48 IU/kg of vitamin E.
[3]Contained 30,000 IU/g of vitamin A, 3000 IU/g of vitamin D, and 44,000 IU/kg of vitamin E.
[4]TM = Trace mineral salt, contained 0.10 % of Mg, 38.0 % of Na, 58.0 % of Cl, 0.04 % of S, 5000 ppm of Fe, 7500 ppm of Zn, 2500 ppm of Cu, 6000 ppm of Mn, 100 ppm of I, and 60 ppm of Se.

TABLE 1. Ingredient composition of diet fed to cows during the covariate period and composition of diets fed to cows during the experimental period that were differing in FNDF percentage and source of starch.

Item	Covariate[1] Diet	21 % FNDF with corn	16 % FNDF with corn	16 % FNDF with corn and wheat	11 % FNDF with WCS
DM	64.2	62.0	64.1	65.4	71.5
		--------------------	% of DM	--------------------	
NDF	34.5	27.5	32.7	33.9	35.6
NDF_{CP}[2]	32.0	25.7	30.0	31.3	33.3
FNDF[3]	16.8	17.8	14.0	13.9	9.4
ADF	18.2	13.9	18.0	18.4	20.1
ADL[4]	3.58	1.68	2.47	1.87	3.00
CP	17.5	17.2	17.9	18.4	17.6
ADIN[5]	0.13	0.10	0.12	0.15	0.13
NDIN[6]	0.40	0.29	0.43	0.44	0.38
Fatty acids	3.35	4.03	3.97	3.92	4.20
Ash	5.94	5.95	5.96	5.96	5.68
NFC[7]	40.9	46.7	41.7	40.0	38.7
Starch	32.8	38.3	29.9	29.9	30.3
Ca	0.89	1.22	1.14	1.15	1.07
P	0.46	0.48	0.44	0.44	0.46
Mg	0.37	0.33	0.35	0.40	0.32
K	1.37	1.43	1.50	1.38	1.35
NE_L, Mcal/kg of DM[8]	1.73	1.88	1.82	1.85	1.78

[1]Covariate = Mineral concentrations are from tabular values.
[2]NDF_{CP} = NDF corrected for protein contamination.
[3]FNDF = forage NDF.
[4]ADL = acid detergent lignin.
[5]ADIN = acid detergent insoluble nitrogen.
[6]NDIN = neutral detergent insoluble nitrogen.
[7]NFC = nonfiber carbohydrates calculated by difference 100 – [NDF_{CP} + CP + ash + (FA/0.90)].
[8]Calculated using Weiss *et al.* (1992, 1998).

TABLE 2. Chemical composition of diet fed to cows during the covariate period and composition of diets fed to cows during the experimental period that were differing in FNDF percentage and source of starch.

Item	*21% FNDF with corn*	*16% FNDF with corn*	*16% FNDF with corn and wheat*	*11% FNDF with WCS*[1]	*SE*[2]
DM intake[3], kg/day	21.5	26.4	22.0	26.7	
FNDF[4] intake, kg/day	3.3^{a}	3.2^{ab}	2.8^{b}	2.3^{c}	0.17
NDF intake, kg/day	5.2^{a}	7.3^{b}	6.5^{b}	9.3^{c}	0.41
Lying, min/day	636	661	630	634	39
Standing, min/day	833	779	810	804	39
Chewing, min/day					
Eating	158	178	141	159	12
Ruminating	396	370	352	353	26
Total	555	547	493	512	27
Chewing,min/kgFNDF					
Eating	49^{a}	55^{ab}	52^{a}	73^{b}	6.5
Ruminating	123^{a}	118^{a}	128^{a}	157^{b}	10
Total	172^{a}	174^{a}	180^{a}	229^{b}	13
Chewing, min/kg NDF					
Eating	31^{a}	24^{b}	22^{b}	18^{b}	2.1
Ruminating	78^{a}	50^{bc}	56^{b}	39^{c}	4.5
Total	110^{a}	74^{bc}	78^{b}	58^{c}	5.5

[a,b,c] Means in a row with different superscripts differ ($P < 0.05$)
[1]WCS = whole cottonseed
[2]SE = standard error
[3]DM intake = calculated for week of observed behavior; not statiscally analyzed
[4]FNDF = forage NDF

TABLE 3: Fiber intake and observed behavior of cows fed diets differing in FNDF percentage and source of starch.

SIEVE SIZE	*21% FNDF with corn*	*16% FNDF with corn*	*16% FNDF with corn and wheat*	*11% FNDF with WCS*[2]	*ALFALFA SILAGE*	*CORN SILAGE*
DM Basis						
300 *um*	97	94	95	95	98	98
600 *um*	90	83	85	86	94	94
1180 *um*	76	54	65	67	84	89
2360 *um*	52	30	33	44	55	73
4750 *um*	19	9	11	24	24	42
MPS[1], mm	2.22	1.41	1.54	2.03	2.68	4.50
As-fed Basis						
600 *um*	97	92	92	89		
1180 *um*	85	73	71	68	95	96
2360 *um*	59	42	41	45	82	88
4750 *um*	31	16	18	27	57	67
MPS, mm	2.99	2.02	2.01	2.21	5.81	5.55

[1]MPS = mean particle size

[2]WCS = whole cottonseed

TABLE 4: Mean particle size and cumulative percent for particles of different sizes in diets differing in FNDF and source of starch.

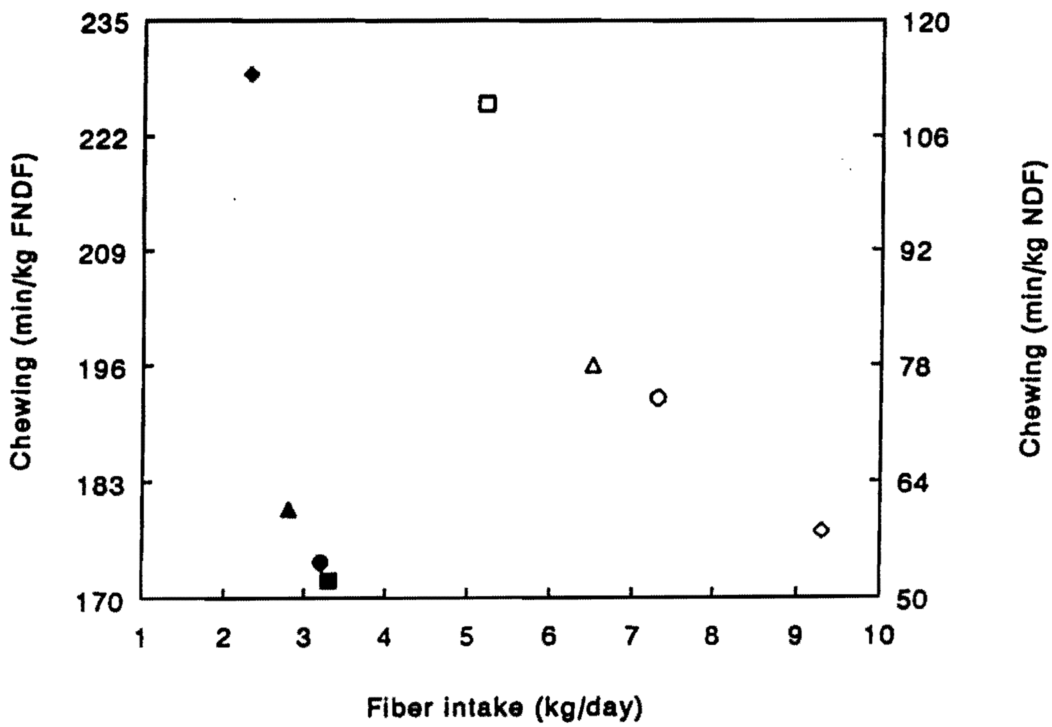

FIGURE 1. Time spent chewing per kg of fiber by cows fed diets differing in percentage of FNDF and source of starch. Legend. 21% FNDF with corn □ NDF ■ FNDF, 16% FNDF with corn o NDF ● FNDF, 16% FNDF with corn and wheat △ NDF ▲ FNDF, 11% FNDF with whole cottonseed ◇ NDF ◆ FNDF

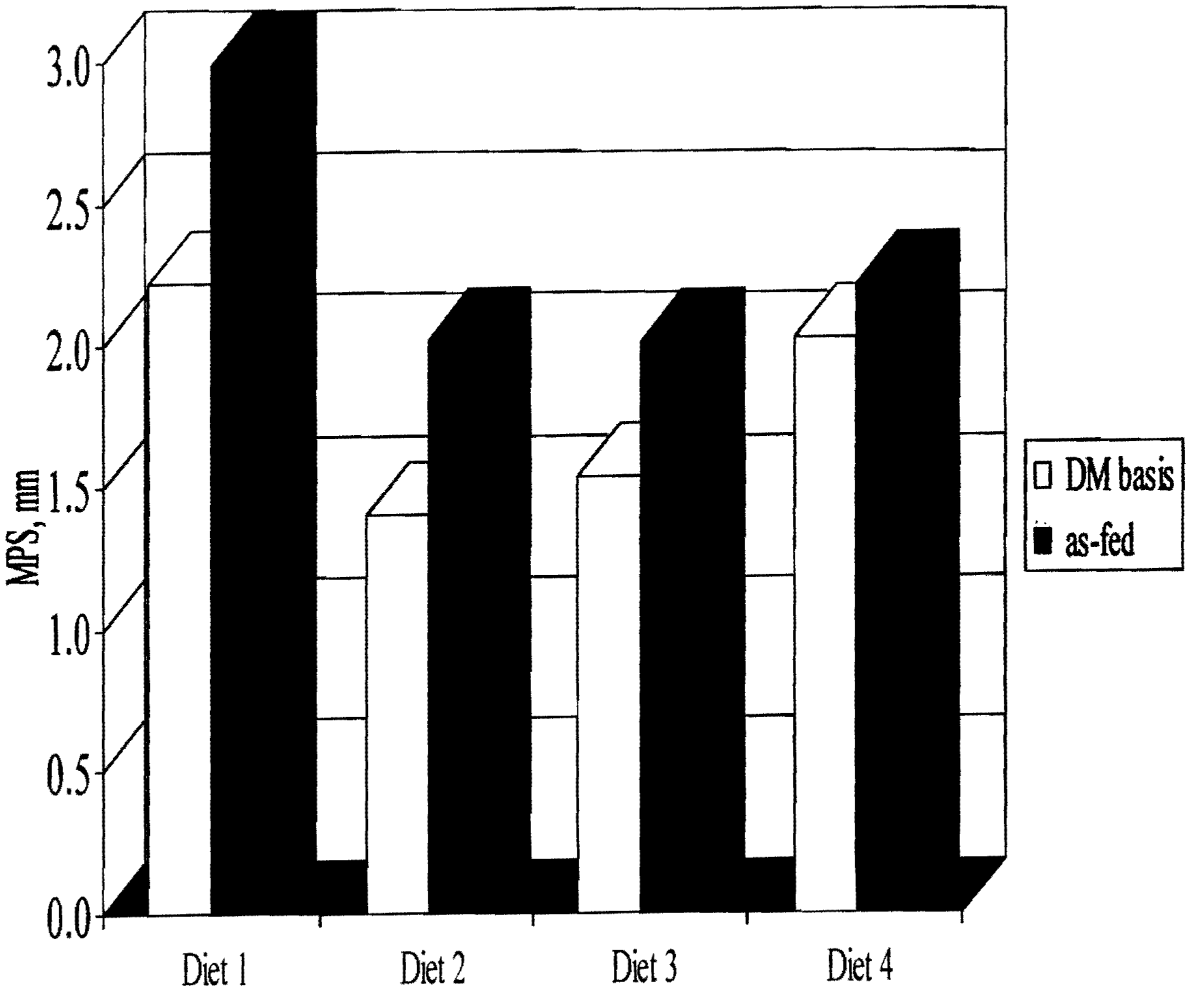

FIGURE 2. Mean particle size (MPS) of diets on an as-fed and DM basis.

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